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HADRON '95 — SUMMARY : PART I

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ABSTRACT

Part I of this summary is concerned with selected results on natural parity states presented at this conference, in particular the glueball candidates the $f_0(1510)$ and $\xi(2230)$. Unnatural parity and exotic states are discussed by Suh-Urk Chung¹.

1. Introduction

The Summary of *Hadron'95* is the same as the summary of all previous Hadron conferences. It is that QCD is the theory of the strong interactions. Though we know this to be true, it is really only in very simple processes, where we have hard scattering, that we can compute with any degree of reliability what QCD has to say. There, where we have short distance interactions, we can use perturbation theory, make predictions, compare them with experiment and find that they agree to a K -factor or two. Such perturbative ideas govern the short-distance part of the inter-quark potential, where simple one gluon exchange dominates, thanks to asymptotic freedom, Fig. 1. However, the bulk of hadronic phenomena are governed by the long-distance regime controlled by confinement. There a whole mesh of gluons are exchanged to produce the force between two quarks, Fig. 1, and we really do not know how to calculate what is going on. It is this region that deter-

Figure 1: The inter-quark potential as a function of separation r . It is controlled by one gluon exchange at short distances and multigluon exchange at long range.

mines the spectrum of light hadrons and indeed all confinement physics. It is from experiment that we primarily learn about this regime. There hadron spectroscopy is the natural guide. It governs not just low energy hadron and nuclear processes, but even high energy scattering. Though the total cross-section for e^+e^- annihilation may be treated perturbatively and even the cross-section for jet production, as soon as we ask the question “what is the probability of finding some specific hadron, like a pion, in a jet”, we must confront confinement and GeV scale physics. The place to learn about this is from the spectrum of light hadrons and in particular in the meson sector, as this is where considerable progress has been made.

We begin our discussion of light mesons with the simple quark model picture with three flavours. Here a quark and antiquark are assumed bound into states whose quantum numbers are determined by the spin, $S_{q\bar{q}}$, of the $q\bar{q}$ system and the relative orbital angular momentum, $L_{q\bar{q}}$, of the quark and antiquark. This leads to the familiar multiplet structure, so readily seen for pseudoscalars, vectors and tensor mesons. Moreover, the mass of an $L_{q\bar{q}} = 0$ meson like the ρ , made of two constituent quarks, is just two-thirds of the mass of the nucleon made of three such quarks. This picture has proved a valuable aid to our understanding.

However, we now have QCD. This seems to complicate matters enormously. A constituent quark, we learn, is really a current quark surrounded by a cloud of gluons and a sea of $q\bar{q}$ pairs. The success of the naive quark picture means that this cloud of gluons is just the same in a ρ meson as in a proton. This gluonic component is in some way universal. The belief that colour is confined and consequently hadrons are colour singlets gives us an understanding of why the mesons we see are made of a quark and an

antiquark and baryons are made of three quarks. However, QCD leads us to expect a far richer spectrum of colour singlet states with mesons made of more quarks, such as $qq\bar{q}\bar{q}$, or hybrid mixtures of quarks and gluons, such as $q\bar{q}g$, and even states with no quarks at all — glueballs, such as gg . Indeed, QCD demands that such states must exist. Thus, the main thrust of experimental studies of the hadron spectrum has for the last twenty years been the search for unambiguous evidence for states beyond the quark model.

2. Scalar mesons

The scalar meson sector is the one that has received most attention at this conference. In Fig. 2 is shown the mass spectrum of $I = 0$, $I = 1/2$ and $I = 1$ 0^{++} states. Those with the black dots alongside have been discussed at this conference ²⁻¹¹. The first thing to decide is how many of these are real and how many are distinct. The candidates for an $f_0(500)$ and $f_0(750)$ (often called σ 's) must, I believe, be unphysical. It is worth spending a minute on this. Hadron states correspond to poles of the S -matrix on the nearby unphysical sheet. The first remark is that they need not have anything to do with poles of the K -matrix. The K -matrix is just a convenience and not a physical quantity. The fact that probability must be conserved in any process means that the S -matrix must be unitary, i.e. $S^\dagger S = 1$. Unitarity demands that resonance poles occurring in one channel must appear in all other channels with the same sets of quantum numbers. This universality means that a resonance that appears in central dipion production in pp scattering must also appear in $\pi\pi \rightarrow \pi\pi$, Fig. 3. It just cannot avoid this. Thus claims of a narrow $\sigma(500)$ in the GAMS results ⁷ cannot be correct as no such state is seen in $\pi\pi$ scattering. Unitarity demands a universality that

Figure 2: The mass spectrum of the $I = 0$, $I = 1/2$ and $I = 1$ 0^{++} mesons. Those with the black dots have been discussed at this conference.

Figure 3: Unitarity requires a resonance, R , that decays to $\pi\pi$, for example, has to couple in the same way to this final state whether produced in $\pi\pi$ scattering or centrally in $pp \rightarrow pp(\pi\pi)$ via a double Pomeron mechanism.

requires central production, for instance, to be analysed in a way consistent with other information on the same channels and not in isolation. I believe we can therefore discount the $f_0(500)$, and in a similar way the $f_0(750)$ ⁸, which is inconsistent with $\pi^0\pi^0$ production in the BNL E852 experiment ¹². The broad scalar state in Fig. 2, denoted by 800-1300, the $f_0(\epsilon(1000))$, is what PDG'94 ¹³ calls the $f_0(1300)$.

Let us turn to the other isoscalar states. As shown in the talks of Stefan Spanier ² and Stefan Resag ³, the Crystal Barrel collaboration have studied $\bar{p}p$ annihilation at rest into $(\pi^0\pi^0)\pi^0$, $(\eta\eta)\pi^0$ and $(4\pi^0)\pi^0$. Analyses of their beautiful Dalitz plots, assuming that the $\bar{p}p$ annihilate purely in a 1S_0 state, requires an $f_0(1510)$ with a width of 150 ± 30 MeV, in addition to an $f_0(1370)$, with a width of ~ 350 MeV and a much larger branching ratio to 4π than to 2π . With 170,000 events in the $3\pi^0$ channel and a similar number with

$\eta\eta\pi^0$, S -wave signals at 1370 and 1510 MeV look very impressive. In the $5\pi^0$ channel, the $f_0(1510)$ signal is less dramatic giving an improvement in the maximum likelihood for both mass and angular distributions over and above the broad $f_0(1370)$.

A major issue is whether the $f_0(1370)$ is really distinct from the equally broad $f_0(1300)$ or not. The answer to this question depends on the particular analysis of the Crystal Barrel results ¹⁴. There are those who say that a single broad scalar stretching from 700 MeV, where it is totally elastic, up to 1400 MeV, where it has become highly inelastic because of the opening of the $\eta\eta$ and appreciable 4π channels, is just as consistent with data as a specifically inelastic $f_0(1370)$ on top of a slowly varying but large background and those who are adamant that a single broad state does not describe the same results ¹⁴. Let us leave this to be resolved.

Whether the $f_0(1510)$ of Crystal Barrel is the same as the $f_0(1525)$ found by LASS ¹⁵ and the $f_0(1590)$ of GAMS ¹⁶ has also been much discussed. Here there is at least a consensus that they may well be the same. The evidence for an $f_0(1525)$ under the well-known $f_2(1525)$, with essentially the same mass and width as the leading D -wave looked highly speculative even in the results of such a high statistics experiment as LASS ¹⁵. But now that Crystal Barrel has definitely seen a scalar in this mass region, it is time to go back and perform a common analysis of this mass region.

Such a combined treatment is the aim of three analyses presented here by Anisovich et al. ⁴, Bugg et al. ⁵, and Anisovich et al. ⁶, in which Sarantsev was a collaborator in each. The aim was to treat the classic data on peripheral dipion production in $\pi^-p \rightarrow \pi^-\pi^+n$, $\rightarrow \pi^-\pi^-p$ from the CERN-Munich group ¹⁷, on $\pi^-p \rightarrow \pi^0\pi^0n$ from GAMS ¹⁸, the Mark III results ¹⁹ on $J/\psi \rightarrow$

$\gamma\pi^+\pi^-\pi^+\pi^-$ together with the Crystal Barrel Dalitz plots on $\bar{p}p \rightarrow \pi^0\pi^0\pi^0$, $\rightarrow \eta\eta\pi^0$ ²⁰ and $\eta\pi^0\pi^0$ ²¹. These simultaneous analyses conclude that there are four 0^{++} isoscalars : the $f_0(980)$, $f_0(\epsilon(1000))$, $f_0(1370)$ and the $f_0(1510)$. An important part of this is the revised opinion of the quantum numbers of the 4π signal in J/ψ radiative decays. This is an illustration of the *metamorphosis* that Achasov ²² talked about and highlights the uncertainty in quantum number determination in complex final states. In these analyses the $\pi\pi \rightarrow \pi\pi$ S -wave cross-section not only has the well-known sharp drop because of the $f_0(980)$ but an analogous one for the $f_0(1510)$. A surprising omission in this treatment is information on $K\bar{K}$ final states, as a major source of inelasticity in the $\pi\pi$ and $\eta\pi$ channels. Forthcoming results from Crystal Barrel may help here too.

3. Which are the $q\bar{q}$ scalars ?

Returning to Fig. 2, the next question to ask is how many $q\bar{q}$ scalar multiplets are there ? Indeed, which states belong to the lowest lying nonet ? The fact that below 1800 MeV there is only one K_0^* , the $K_0^*(1430)$ found so cleanly by LASS ²³, unambiguously points to only one $q\bar{q}$ multiplet in this mass region despite the two a_0 's and very many f_0 's. To help decide which are $q\bar{q}$ states, let us consider a case study.

We start from the well-known nine lightest vector mesons with the spectrum shown in Fig. 4. There is a one-to-one correspondence between the observed mesons and the underlying ideally-mixed quark model nonet. This is the success of the quark model. Let us see why. One begins with the bare quark state propagators with denominators $(m_0^2 - s)$. Rather like a K -matrix element these bare propagators have poles on the real axis at

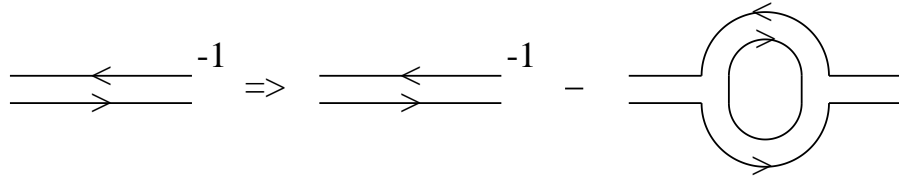
Figure 4: 1^{--} ideally mixed $q\bar{q}$ nonet and the corresponding meson states.

$s \equiv E^2 = m_0^2$. Now we switch on interactions, Fig. 5. This allows the $q\bar{q}$ states to couple to hadronic final states (which is what accounts for their decays) and produces hadron loops in their propagators. The effect of these on the inverse propagators is to change the zeroth order result $(m_0^2 - s)$ to $\mathcal{M}(s)^2 - s - i\mathcal{M}(s)\Gamma(s)$. The poles in the propagator have moved into the complex plane as displayed in Fig. 6 and there are branch cuts at each hadronic threshold. Now the $I = 0$ states, for example, can couple to 3π and $K\bar{K}$.

The bare propagator for an $s\bar{s}$ corresponds to a non-decaying ϕ , i.e.

$$|\phi\rangle_0 = |s\bar{s}\rangle \quad .$$

Turning on interactions one finds that the physical ϕ has a Fock space de-



$$m_0^2 - s \Rightarrow M(s)^2 - s - i M(s)\Gamma(s)$$

Figure 5: How the inverse propagator for a bare $q\bar{q}$ state changes when its couplings to hadrons are included.

Figure 6: The complex s -plane for the states of Fig. 5. The bare propagator has a pole on the positive real axis. The dressed propagator has a pole below the real axis and the plane has cuts generated by the hadronic intermediate states in the loop of Fig. 5.

composition as

$$|\phi\rangle_1 = \sqrt{1-\epsilon^2}|s\bar{s}\rangle + \epsilon_1|K\bar{K}\rangle + \epsilon_2|\rho\pi\rangle + \dots,$$

where $\epsilon^2 = \epsilon_1^2 + \epsilon_2^2 + \dots \ll 1$. Consequently, the physical ϕ is overwhelmingly an $s\bar{s}$ state, just like the bare one, and the switching on of interactions produces a relatively small effect. Then the simple quark picture works. We observe hadrons, but we can nevertheless readily infer their quark substructure. A similar picture holds for tensor mesons. Now let us turn to the scalars.

Figure 7: 0^{++} ideally mixed $q\bar{q}$ nonet with the corresponding meson states in the dynamical scheme of Tornqvist ⁹.

As an illustration, we start from an ideal quark model nonet as in Fig. 7 with the non-strange quark states around 1420 MeV and replacing the u or d with an s quark adds 100 MeV to the mass. Let us now turn on the coupling to hadrons as in Fig. 5, but this time just to two pseudoscalars. This is the explicit calculation performed by Tornqvist ⁹. What makes the situation different from that for vectors and tensors is firstly that the coupling to $\pi\pi$, $\eta\eta$ etc. are larger and secondly the thresholds for $0^{++} \rightarrow 0^{-+} 0^{-+}$ are S -wave. So including just the two pseudoscalar decays, the outcome is dramatically different from that outlined for the vectors. The physical states are shown in Fig. 7, in which the $f_0(1200/1300)$ is broad and the $a_0(980)$ and $f_0(980)$ appear narrow because of their proximity to $K\bar{K}$ threshold. These first approximations to the physical states can similarly be decomposed into Fock space. Now, for example :

$$|f_0(980)\rangle_1 = \epsilon_1 |s\bar{s}\rangle + \sqrt{1-\epsilon^2} |K\bar{K}\rangle + \dots$$

Once again $\epsilon_1^2 < \epsilon^2 \ll 1$, but now the $f_0(980)$ is largely a $K\bar{K}$ state and not an $s\bar{s}$. This should not be confused with a $K\bar{K}$ molecule, as here the *seeds* are definitely quark model states, and the $f_0(980)$ is not bound by inter-hadron forces alone ²⁴.

Tornqvist's valuable model calculation serves as a serious warning. It highlights how in the scalar sector no close relationship between the observed hadrons and the underlying quark states is to be simply seen. It is, however, important to recognise that Tornqvist's calculation is a model : a particular unitarisation is used, only two pseudoscalar channels, $\pi\pi$, $K\bar{K}$, $\pi\eta$, ... , are included and there are only the nine *seeds* of a simple quark model multiplet. Questions abound : what is the role of 4π channels, which for primitive states

at 1500 MeV must be important ? What happens if one introduces a purely gluonic *seed* too ? This is clearly a territory awaiting further exploration.

At this conference, we have also heard about the work of Amsler and Close ¹⁰ on the same 0^{++} sector. The quark model *seeds* are here nine $q\bar{q}$'s and one gg . The mixing of these primitives is calculated in old-fashioned perturbation theory. The outcome is that the $f_0(1510)$ is the predominantly glue state. This calculation is non-relativistic and not at the level of sophistication of Tornqvist's dynamical treatment. Nevertheless, it serves as an alternative hypothesis, which is illustrated in Fig. 8.

Consider all the scalar states of Fig. 2 and assume that the f_0 's at 1510, 1525 and 1590 MeV are really all the same, then Tornqvist's picture relates the nine lightest hadron states to the $S_{q\bar{q}} = 1$, $L_{q\bar{q}} = 1$ quark multiplet. As seen in Fig. 8, this leaves the $f_0(1370)$, the $a_0(1430)$ and the $f_0(1510)$ without a home. These are then extra states — one of which may well be a glueball. In contrast, the Amsler-Close scheme ¹⁰, with its glueball *seed* built in, has slots for ten states. One of these is a predominantly $s\bar{s}$ scalar above 1700. This they suggest is the $f_0(1710)$ — the erstwhile θ . Again this is one of Achasov's *metamorphoses* ²² where the $I = 0$ state at 1710 MeV seen in J/ψ decays started out as a tensor, then became a scalar and is perhaps now a mixture of the two spins ¹³. Clarification is needed. Even given this, the Amsler-Close picture leaves the scalars near $K\bar{K}$ threshold, the $a_0(980)$ and $f_0(980)$, out in the cold (Fig. 8), together with the broad $f_0(1300)$, if this is really distinct from the $f_0(1370)$. One has to appeal to other *seedings* to account for the a_0 , $f_0(980)$, like $K\bar{K}$ -molecules or Gribov minions. To me this looks unlikely. We need a more sophisticated approach to the scalars, as Tornqvist has highlighted, before we can reach any more definite conclusion

Figure 8: Comparison of the observed spectrum of 0^{++} mesons with (I) the scheme supported by Tornqvist's calculation ⁹ and (II) the scheme of Amsler and Close ¹⁰.

than there are more scalars than can fit into a simple quark model scheme. The $f_0(1510)$ with its width of ~ 120 MeV is certainly distinct from the very broad $K_0^*(1430)$ and $f_0(1300/1370)$ states. It is therefore very definitely a candidate for an *extra* or gluonic scalar. Once again information on its $K\bar{K}$ couplings will be vital to ascertain its nature.

4. ¿ Tensor glueball ?

As soon as glueballs are mentioned, one must, of course, report on lattice calculations. These give the following numbers for scalar and tensor glueball masses^{25,26} in quenched QCD :

0^{++}	1740 ± 70 MeV	IBM
	1550 ± 50 MeV	UKQCD
2^{++}	2270 ± 100 MeV	UKQCD

To the outsider the different groups do not appear to have inconsistent predictions for the gluonic scalar, but each group argues for its value furiously. So much so that one has the impression that experimenters should be having many sleepless nights if they do not find results in total agreement with one lattice group or the other. However, it is important to reiterate that these calculations are for *quenched* QCD, so that there is no coupling of the primitive glueball to quarks. We have seen from Tornqvist's calculation that the coupling of scalars to two pseudoscalars may have a dramatic effect on the behaviour of the scalar propagator and though this was in the quark sector, it may nevertheless have some significance for the glueball case too.

Nonetheless, a scalar at 1510 MeV seems to me quite consistent with lattice estimates.

Work on the lattice also leads us to expect a tensor glueball above 2 GeV and at this meeting we heard Jin ²⁷ present evidence from BES of a candidate the $\xi(2230)$. This state was previously seen as a narrow spike in $J/\psi \rightarrow \gamma K^+ K^-$ and $K_s K_s$ by Mark III ²⁸. What BES have added is not really a more pronounced signal, but rather a consistent structure in more radiative J/ψ decay channels : in $\pi^+ \pi^-$, $K^+ K^-$, $K_s K_s$ and $\bar{p} p$ ^{29,27}. All are consistent with a resonance of mass 2235 ± 10 MeV and width of 20 ± 12 MeV. Now it is argued that this is a tensor glueball candidate ²⁷. However, it is quite unclear whether it is a tensor and whether it is a glueball. 2^{++} is merely assumed. There is no doubt the state is narrow, but what about its branching ratios ? From the lack of signal for the ξ in LEAR's PS185 experiment ³⁰, one can infer that

$$\text{Br}(\xi \rightarrow \bar{p} p) \cdot \text{Br}(\xi \rightarrow K \bar{K}) < 10^{-4} \quad .$$

Combining this with their own results, BES ²⁷ infer

$$\text{Br}(\xi \rightarrow \pi^+ \pi^-) , \text{Br}(\xi \rightarrow K^+ K^-) < 2\% \quad .$$

These are very small, but in fact they are very much in keeping with the branching ratios for χ_{c0} and χ_{c2} , whose decays are believed to proceed through intermediate gluons. Before any conclusions can be drawn, one must determine what the other $\sim 90\%$ of decays are. Are any of these dominant ? There are those that have argued that a glueball should have important $\eta\eta$, $\eta\eta'$ and $\eta'\eta'$ decays ³¹ ? Others have suggested that a glueball being a flavour-singlet would have branching ratios in well defined fractions, so that

$K\overline{K} : \pi\pi : \eta\eta : \eta\eta' \simeq 4 : 3 : 1 : 0$. Even its quantum numbers are uncertain. Indeed, the $\xi(2230)$ sits exactly at $\Lambda\overline{\Lambda}$ threshold — what is its relation, if any, with that channel ? All this we need to know before we can conclude that the $\xi(2230)$ is a tensor and is a glueball. *Prima facie* evidence that it is not a $q\overline{q}$ state is provided by its very narrow width. A simple OZI suppression rule would suggest that the width of a tensor glueball is related to that of the χ_{c2} and a typical $q\overline{q}$ tensor, like the $f_2(1270)$, by

$$\Gamma(G) \simeq [\Gamma(\chi_{c2}) \Gamma(f_2)]^{1/2} \quad .$$

In round numbers the width of the χ_{c2} is 2 MeV, the f_2 is 200 MeV, so one would expect $\Gamma(G) \simeq 20$ MeV, with which BES, of course, agree. All this is most intriguing, but we clearly need much more experimental information.

Thus, we have had two glueball candidates presented at this conference : the scalar $f_0(1510)$ and a tentatively tensor $\xi(2230)$. We see that they have quite different characteristics. The scalar has a typical hadronic width of 120 MeV or so, while the ξ is very narrow ~ 20 MeV. Why should these states be so different, if they are both glueballs ? The naive argument is to look at their position relative to the lowest $q\overline{q}$ nonet. Whether the scalar nonet, Fig. 8, is as Tornqvist⁹ has it or is that of Amsler and Close¹⁰, the $f_0(1510)$ is very nearby and naturally mixes with these states. Consequently, a gluonic state would mix with the $q\overline{q}$ states and thereby decay readily into hadrons with a typical 100 MeV width. In contrast, the $\xi(2230)$ is well above the well-known tensor nonet and the mixings are consequently much smaller and a purer gluonic hadron with a narrow width may result. Of course, this has to be backed by realistic dynamical calculations. It begs one immediate question, which is : yes, a tensor glueball at 2.2 GeV may mix only a little with the ground state tensors, but why could it not mix more with nearby

radially excited states and so become broader too ? We know so little about radially excited states, that it is difficult to answer this sensibly.

Tests of the nature of the $f_0(1510)$ and of the $\xi(2230)$ are essential. Information on their couplings in J/ψ radiative decays are the basis of the Çakir/Farrar test ³² and their widths into $\gamma\gamma$ would allow the Chanowitz *stickiness* test ³³ to be applied — these are for the future.

5. Decays

Now let us turn to the topic of decay systematics. Ackleh, Barnes and Swanson ³⁴ have persuasively shown how hadron decays by the creation of a $q\bar{q}$ pair in a 3P_0 state beautifully correlates a large amount of information. Thus it predicts the right S/D ratio for $b_1 \rightarrow \omega\pi$ and provides a very interesting rule that a state with $q\bar{q}$ spin of zero cannot decay into two similar quark spin zero mesons, i.e $S_{q\bar{q}} = 0 \not\rightarrow S_{q\bar{q}} = 0 + S_{q\bar{q}} = 0$. This very nicely explains why the

$$\begin{aligned} \pi_2(1670) &\not\rightarrow b_1\pi \quad , \\ &\rightarrow \rho\pi \ , \ f_2\pi \quad , \end{aligned}$$

which hold experimentally. The theoretical basis for this picture is that pair creation by the scalar confining part of the inter-quark potential, Fig. 1, produces the $q\bar{q}$ in a 3P_0 state. Indeed, the relative magnitudes of all decays are predicted. All this works remarkably well — except for the scalar sector, perhaps not surprisingly..

To deal with this, Ackleh et al. ³⁴ add to the 3P_0 component a contribution from just one gluon exchange even though the coupling has to be large

(cf. Fig.1 at large distances). They find that this simple addition eases the problem in the scalar decays, while leaving everything else unchanged. Of course, this cannot be the complete story. The whole problem of soft physics is non-perturbative and so the appropriate framework for solving these issues is through the study of Bethe-Salpeter amplitudes, which automatically include the non-perturbative behaviour of quark and gluon propagators and vertices that satisfy the Schwinger-Dyson equations. I want to do nothing more than advertise the recent progress in this approach ³⁵. One of its successes is its ability to incorporate the Goldstone nature of the pion in a natural way. Chiral symmetry breaking is an important feature of the real world ³⁶, which is far from obvious in a simple $q\bar{q}$ picture of the pion.

6. The S -matrix determines Physics. Does Physics fix the S -matrix ?

I now want to comment briefly on the key problem of getting physics out of experiments. It is clear that physics predicts uniquely what experiment sees. However, given experimental information the extraction of physics from this is fraught with ambiguity. This is one of the reasons why it is essential to have many sources of information focussing on the same physics issues. Thus, we want to use all of e^+e^- annihilation, peripheral πN and KN scattering, central production in πp and pp collisions, $\bar{p}p$ annihilation and J/ψ decays to learn about the hadron spectrum. At this conference the results from LEAR have rightly played a central role, but they on their own are not enough.

The standard way to analyse $\bar{p}p$ annihilation into some multi-hadron final state, e.g. $\bar{p}p \rightarrow ABC$, is to use the Isobar model. This assumes that

resonances only occur in the two-body channels AB with C as a spectator, or BC with A as a spectator or CA with B as a spectator. These two body channels are often $\pi\pi$, for example. Unitarity requires that the coupling of any resonance to $\pi\pi$, however produced, must be universal, Fig. 3 again. Then the $\bar{p}p$ amplitude, \mathcal{F} , is intimately related to the amplitude, \mathcal{T} , for $\pi\pi \rightarrow \pi\pi$ with the same quantum numbers. This means for the *cogniscente* that P , or Q - vectors ^{37,38} (or coupling functions α ³⁹) which relate \mathcal{F} to \mathcal{T} must be real, since by the isobar assumption the third final state particle is a spectator. Of course, the isobar model is not exact and so the relation is, in principle, not so simple. However, it is not obvious that just making the vectors P , Q or α complex, as is often assumed, is the only consequence. Multi-body final state interactions are more complicated than that.

Though the Crystal Barrel data may be beautifully described making such assumptions, there are indications that the world may indeed be a more dangerous place. Chris Pinder ¹¹ described the Crystal Barrel analysis of their $\bar{p}p \rightarrow \eta 3\pi$ data. There he reported that 60% of the events were 4-body phase space. Is it just an accident that this channel alone needs multi-body interactions and that they are not present in any other ? Maximum likelihood analysis of very many channels does show that only 2-body (isobar) interactions are needed, but is that the only criterion for deciding what clues nature is offering ? More theoretical and phenomenological work is needed. Despite these potentially serious *caveats* about analyses, the beautiful data from LEAR, and Crystal Barrel in particular, have had a dramatic impact on this field. It is tragic that this must end so soon.

7. Conclusions

At *Hadron'95* glueball candidates have been sighted. We need to await the next meeting before we can be sure of all the details, but the $f_0(1510)$ and the $\xi(2230)$ presently fail to fit into $q\bar{q}$ multiplets. They are certainly candidates for that something extra — the glue at the the core of QCD. Time will tell.

Acknowledgements

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